Modeling rough sea effects on seismic data using mimetic finite differences

Tugrul Konuk and Jeffrey Shragge

Center for Wave Phenomena
Egorov et al. (Geophysical Prospecting, 2017)
available modeling approaches

- Kirchhoff-based approximations
- finite-differences (FD)
- finite-elements (FE)
seismic modeling in complex geometry

Cartesian \((x^i)\)

Physical Mesh

FD or better

- full seismic wavefield
- dynamic surfaces
- no explicit meshing
- uniform accuracy
- numerical stability
- efficiency
seismic modeling in complex geometry

$g_{ij}$

Cartesian ($x^i$)
Physical Mesh

Generalized ($\xi^i$)
Computational Mesh

Shragge and Tapley (Geophysics, 2017)
time-varying grids

Konuk and Shragge (CWP Report, 2018)
Can we extend this method to time-varying meshes?

Is this method numerically stable?
sea surface

- measure
  - satellite altimetry
  - drone or UAV
- image
  - Orji et. al. (2011, 2013)
- model
  - Pierson-Moskowitz

\[ S(\xi^1, \xi^2, t) \]
sea surface

- measure
  - satellite altimetry
  - drone or UAV
- image
  - Orji et. al. (2011, 2013)
- model
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- pass to FD acoustic solver
  - calculate $g^{ij}$ implicitly

$$S(\xi^1, \xi^2, t)$$
<table>
<thead>
<tr>
<th></th>
<th>conventional FD</th>
<th>mimetic FD</th>
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<tbody>
<tr>
<td>conservation laws</td>
<td>do not honor</td>
<td>mimic continuous operators</td>
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<td>boundary accuracy</td>
<td>$&lt; \text{interior}$</td>
<td>$= \text{interior}$</td>
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<td>long-term stability</td>
<td>unstable</td>
<td>stable</td>
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<td>discretization</td>
<td>SSG or FSG</td>
<td>FSG</td>
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rough sea effects on ghosts and multiples

- sea surface velocity is 19 m/s
- 4 m maximum wave height
- source wavelet is 40 Hz Ricker
- water depth is 150 m
- water velocity is 1500 m/s
The diagrams illustrate the comparison between a flat time-varying medium and a time-varying medium. The left diagram represents the flat case, while the right diagram shows the time-varying medium. The yellow square highlights the region of interest in both cases.
The diagram compares flat and time-varying time-separation functions. The left panel shows a flat function with constant time-varying intervals, while the right panel illustrates a time-varying function with varying time intervals across the offset range.
SRME

Bale and Wilkinson (2016)

FWI

Shen et al. (2017)

4D

Chadwick and Noy. (2017)

LSRTM

Duval et al. (2013)
conclusions

- rough seas may pose processing challenges
  - deghosting, SRME, FWI, RTM, time-lapse,...
- modeling with dynamic sea surface
  - stable solutions require FSG + MFD
- significant imprint on seismic data
  - phase difference, amplitude (de)focusing, lateral variability
BACKUP SLIDES
standard staggered grids (SSG)
fully staggered grids (FSG)
free-surface

\[ \xi_1 = 0 \\
\xi_2 - \Delta \xi \\
\xi_2 - \Delta \xi \\
\xi_2 - \frac{\Delta \xi}{2} \\
\xi_2 = 2\Delta \xi \]
instabilities in boundary regions

Shragge (SEG, 2017)
free-surface

\[ \xi_1 = 0 \]
\[ \xi_2 - \Delta z \]
\[ \xi_3 - \Delta z \]
\[ \xi_4 - \frac{\Delta z}{2} \]
\[ \xi_5 = 2\Delta z \]
mimetic operators

\[ \xi_1 = 0 \]
\[ \xi_2 = \frac{\Delta \xi}{2} \]
\[ \xi_2 = \Delta \xi \]
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\[ \xi_2 = 2\Delta \xi \]